



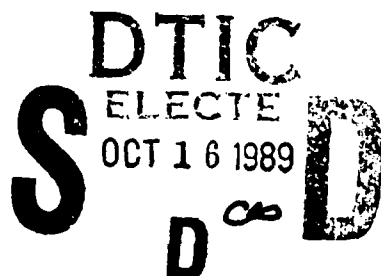
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## PHASE I REPORT

### US ARMY SMALL BUSINESS INNOVATIVE RESEARCH PROGRAM

### ULTRASONIC ENHANCED CLEANING OF FOULED MEMBRANE ELEMENTS FITTED WITH INNOVATIVE SPACERS

Contract No. DAAK70-87-C-0041  
Belvoir Research, Development & Engineering Center  
Fort Belvoir, Virginia 22060-5606



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19 ABSTRACT (Continue on reverse if necessary and identify by block number) This report is a Small Business Innovative Research (SBIR) project to study the benefits of ultrasonics and/or new spacers to enhance cleaning fouled reverse osmosis elements. The study shows that the spacers if properly designed can reduce fouling significantly. Ultrasonics have been shown to be feasible as a method of enhancing rapid cleaning especially with the new more effective spacer. Resonating the water is more effective than resonating the construction material. Further research is recommended to develop specific designs to optimize the cleaning process.					
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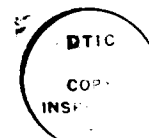
## PREFACE

V.J. Ciccone & Associates, Inc. (VJCA) conceived, developed and applied equipment and experimental procedures related to the fouling and Ultrasonic Assisted Cleaning of water treatment membranes. This effort was sponsored by a Phase I Department of Defense Small Business Innovative Research Program (SBIR) award, through the Belvoir Research, Development and Engineering Center (BRDEC), Ft. Belvoir, Virginia.

The authors acknowledge and thank Mr. Don Lindsten and Mr. Drew Downing, both of BRDEC, for their advice and support during this Phase I project.

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## 1.0 INTRODUCTION

### 1.1 Identification and Significance of the Problem:

Currently US Army field water purification units called Reverse Osmosis Water Purification Units (ROWPU), include expensive and unwieldy pretreatment sub-systems. Membrane element fouling is currently one of the most costly maintenance problems facing the ROWPU. All RO elements foul even with relatively clean water and depending on the skill of the operator can be cleaned to some degree by chemical methods. The fouling is irreversible and performance losses of approximately 5% are incurred for each cleaning cycle. This means that after two or three cleaning cycles, RO elements have to be replaced due to lack of effectiveness. The Army has been attacking the problem on several fronts including the examination of new pretreatment systems to remove the foulants, new element designs to make cleaning easier, and new cleaning systems which are simpler and more effective.

This Phase I SBIR deals specifically with the application and feasibility of new or alternative cleaning systems. In the early stages of this effort it was decided that it would be beneficial and profitable to approach the research by examining a combination of new effects. Since it is not technically feasible to disassemble new reverse osmosis elements and observe changes to the internal structure, it was jointly decided (i.e. between BRDEC and VJCA) that for this Phase I feasibility study it would be more cost effective and quicker to examine the feasibility parameters using ultrafiltration membranes. There were four reasons for this approach: First the UF membrane elements could be easily reconfigured simply by unrolling and replacing the internal spacers. Second, the UF is the most effective new pretreatment system under consideration for use on the ROWPU, and through its use the cleaning cycle is moved from the RO element sub-system to the pretreatment UF element sub-system. Third, if cleaning of the UF elements is enhanced, the UF pretreatment system can be more effectively used in combination with the RO elements as an efficient and economical total system. Fourth, in the interest of both reducing testing time and working within budget constraints, the UF system could be more easily fouled (i.e. loaded with silt more rapidly) because of the high throughput of water.

The protocol which was developed for this investigative effort was to grossly foul the UF elements, study their cleaning using ultrasonic enhanced techniques, establish feasibility and translate those results to a predicted impact upon the RO elements and sub-system to be actually implemented in the Phase II study. It is believed that the demonstration of an effective

cleaning system and/or new spacer design for the UF sub-system will lead to a more effective RO operation through a significant extension of the RO element life and an ultimate savings in operational costs.

## 1.2 Objectives

The objectives of this SBIR Phase I project concerned the interrelated questions of how to minimize membrane fouling during operations with turbid feedwater and to demonstrate enhanced cleaning of fouled membranes using ultrasonic technology. The specific objectives are listed below:

- a. A factor in current element design which may contribute to fouling is the use of a lattice-work type of plastic spacer which separates the leaves of spiral-wound membrane elements. The feedwater, under pressure, is forced over or under the spacer. It is theorized that as the water flows through the narrow openings between the spacer and the membrane it undergoes a Bernoulli-type acceleration followed by cavitation on the downstream side of the spacer. This in turn leads to deposition of and considerable packing of suspended detritus (**Figure 1**).
  - An objective of this study was to determine the relative effectiveness of different spacers under conditions of highly turbid feedwater.
- b. As feedwater passes across the surface of ultrafiltration membranes, dispersed and suspended solids are caught in the webbing of the spacers and agglomerated onto the membrane surface. The effective removal of this foulant requires that such agglomerated "cakes" be pulverized. Once this is accomplished the dispersed material can be removed by entraining it in the flushing water.
  - A second objective of this study was to determine the relative effectiveness of membrane cleaning protocols including:
    - the vertical orientation of membranes so that gravitational forces might offer some advantage.
    - the coupling of ultrasonic energy through the water media to the ultrafiltration membrane in such a way as to enable this energy source to mechanically loosen and disperse foulant particles.

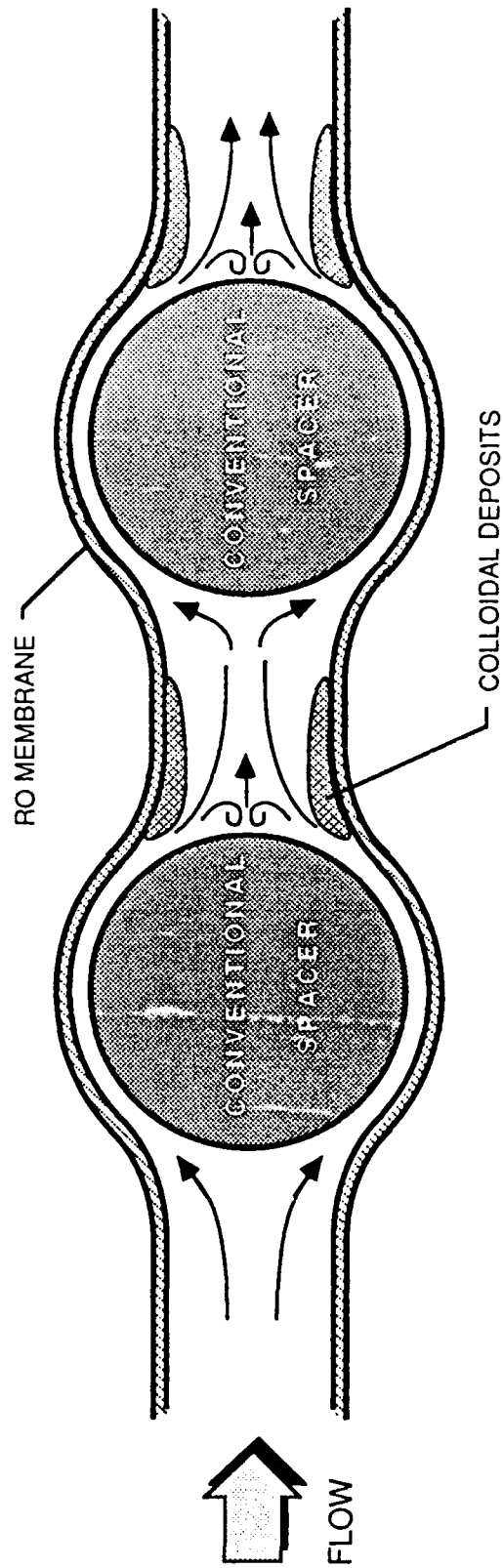


Figure 1  
DEPOSITION OF COLLOIDAL AND OTHER PARTICLES  
ONTO SURFACE OF RO MEMBRANE

- c. A fouled membrane will have its surface covered with packed solids which lowers access of feedwater to the membrane and reduces product yield. However, the effectiveness of the membrane may be essentially completely restored once that cake has been removed. Since the deposited materials will significantly increase the weight of the fouled element, the weight loss on cleaning can be used as a measure of cleaning efficiency.
- A third objective of this study was to determine the degree to which membrane cleaning was accomplished as measured by the weight loss after the ultrasonic enhanced cleaning and product water performance (i.e. yield).

## **2.0 TECHNICAL APPROACH**

### **2.1 Literature Search**

An extensive literature search was conducted to develop technical information relative to the applications of ultrasonic energy to surface cleaning activities. Sources of information included the VJCA in-house library, other technical libraries, technical literature and private discussions obtained from various vendors of ultrasonic equipment, and from BRDEC. A complete bibliography is provided in Section 6.0.

### **2.2 Location of Laboratory Work**

All work was done in the VJCA laboratory facilities in Woodbridge, VA., during August, 1987 through February, 1988.

### **2.3 Water Source**

A 2000 liter PVC reservoir tank was filled with approximately 1200 liters of tap water. A sump pump was submerged in this water to provide agitation. The water then was "muddied" and used as the source of feedwater. In this manner a fully suspended colloidal mixture was constantly maintained (Figure 2-1).

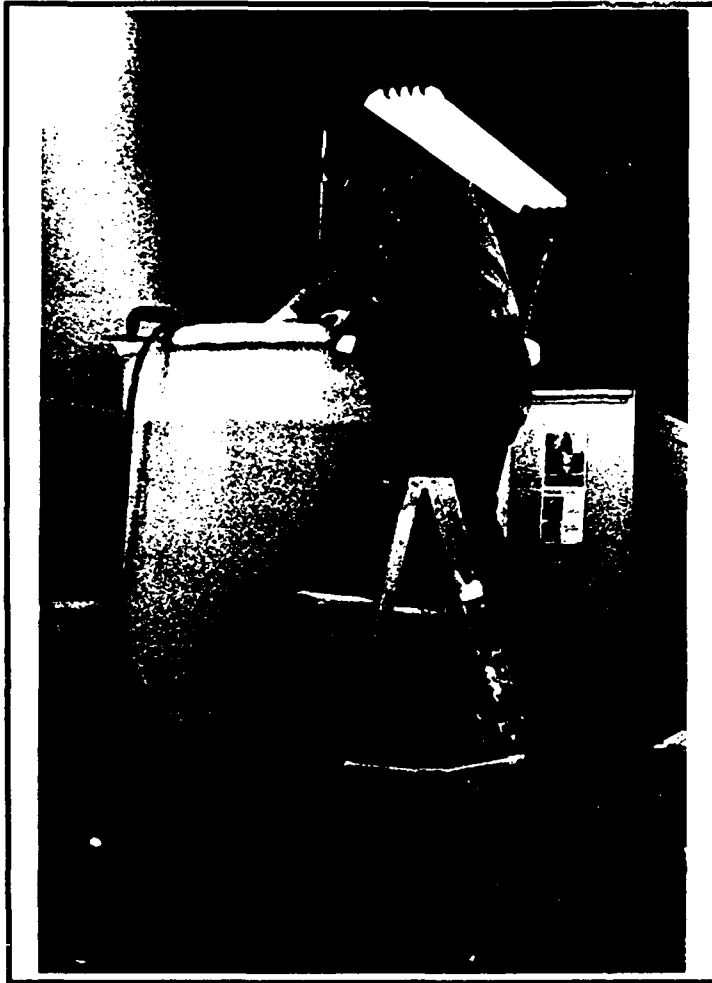
The turbidity of the water in this reservoir tank was made up with clay from some natural Northern Virginia soil. Desired turbidity levels were accomplished by suspending this soil in the reservoir as noted above.

### **2.4 Pressure Vessel Configuration**

Four membrane pressure vessels were constructed for this project. Each employed the fundamental design and plumbing of the ROMEM. Two of the pressure vessel walls were made of stainless steel, two of PVC. Endplates were made of PVC (Figure 2-2).

Feed water to the pressure vessels was pumped from the reservoir tank through a single header to the ROMEM manifold serving each of the vertically arranged pressure vessels. Feedwater pressure was monitored by an in-line pressure guage. Feedwater flow to each pressure vessel was accomplished through separate lines. Pressure in each line was monitored by separate, in-line pressure guages. Valves on each line allowed the operator to control the flow of water to any individual unit.

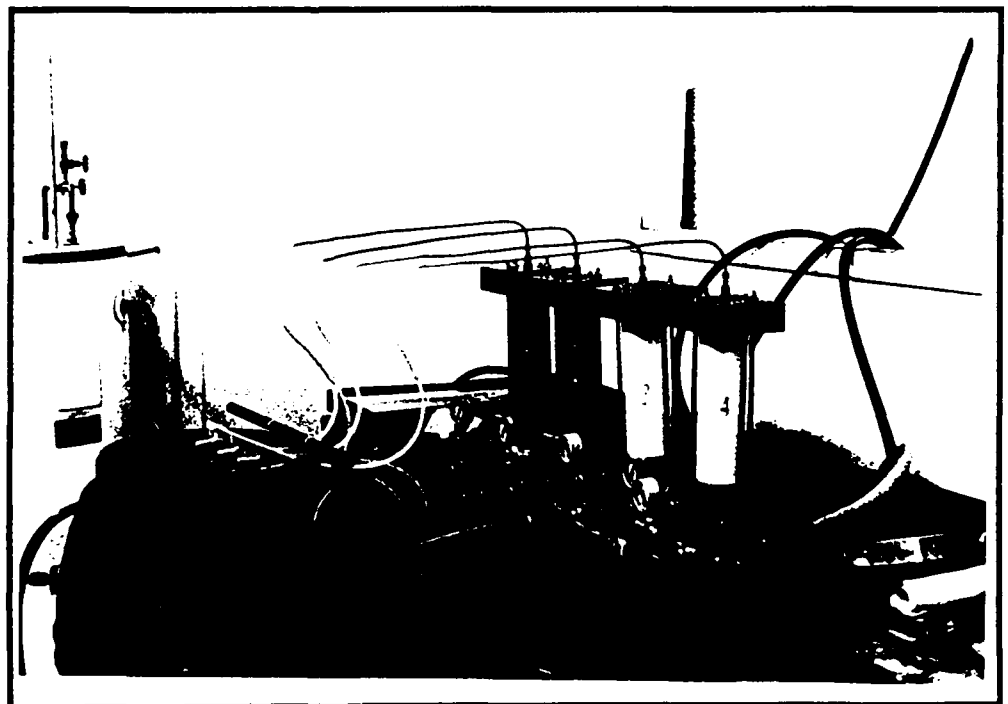
FIGURE 2-1



ADJUSTING TURBIDITY IN WATER  
OF THE 2000 LITER RESERVOIR  
TANK

FIGURE 2-2

ARRANGEMENT OF  
FOUR ROMEM-TYPE  
PRESSURE VESSELS  
USED IN THIS  
EXPERIMENTAL DESIGN



The product water was collected from the top portion of the unit, while the brine was collected from within the ROMEM base. A regulator valve on each brine line allowed the operator to adjust the flow of brine and, therefore, the operating pressure within the pressure vessel.

The brine and product flow of each pressure vessel returned via separate lines to a 200 liter receiving tank where the rate of flow in each line was measured (see details, section 2.5). The combined waters then were pumped back into the reservoir tank for remixing and recirculation (see Figure 2-3).

## 2.5 Measurements

Seven parameters pertaining to each pressure vessel were monitored throughout the duration of this study. Data were processed through the use of three VJCA computer programs. Details are provided below:

- a. Turbidity: Turbidity was determined for each brine and product water stream and in the reservoir tank each time a measurement sequence was initiated. Turbidity was measured using standard practices associated with the use of a Hach Model 2100A Turbidometer, standardized by use of sealed, standard samples from Hach (#12684-00) (Figure 2-4).
- b. Brine water weight: Because of the relatively low brine flow range, a Mettler P163 top-loading electric balance was used to weigh samples to the nearest milligram (Figure 2-5).
- c. Product water weight: The product water flow rates were measured by collecting approximately one-half gallon of water over a one minute span of time. The water then was weighted on a Chatillon top-loading platform balance to the nearest 0.05 lbs. (Figure 2-6).
- d. Time: All time measurements were made using a stop watch capable of reading to the nearest .01 second.
- e. Pressure: Feed water and brine line pressures were measured using in-line pressure gauges with a 0 to 200 psi range. Each was capable of being read to the nearest 2 psi., interval.
- f. Temperature: Temperatures for brine and product water were determined for each measurement using an Ashcroft probe thermometer capable of reading to nearest 1°F.



FIGURE 2-3



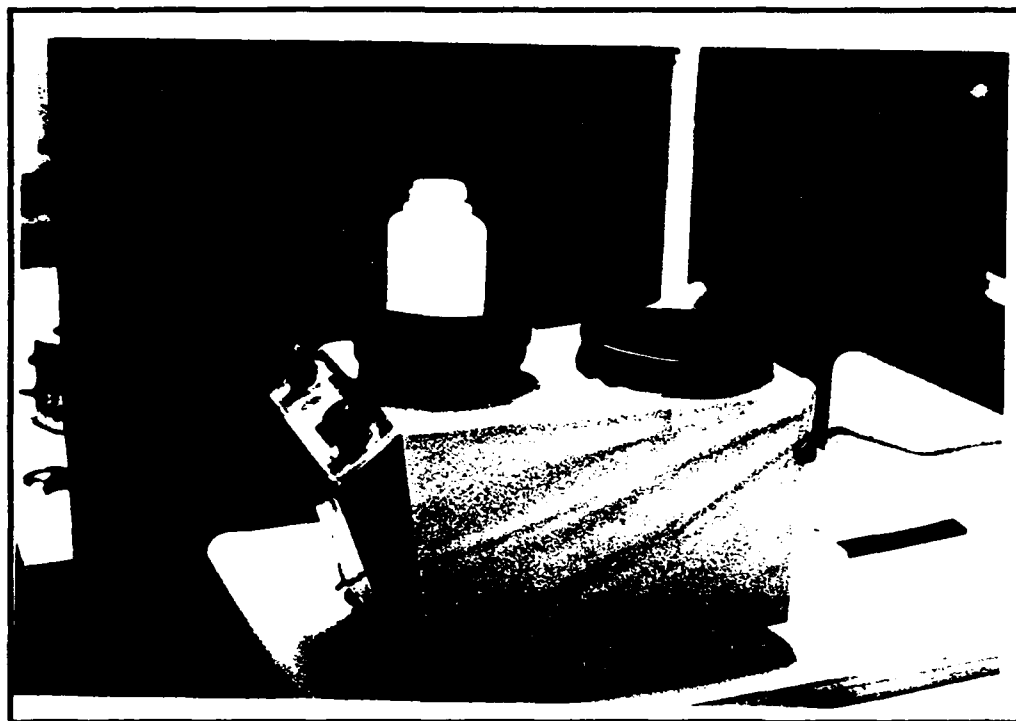
COLLECTING PRODUCT SAMPLE  
FROM UF FILTER OUTPUT OVER THE  
RETURN RESERVOIR

FIGURE 2-4

ANALYTICAL BALANCE  
(LEFT) AND HACH  
TURBIDOMETER (RIGHT)



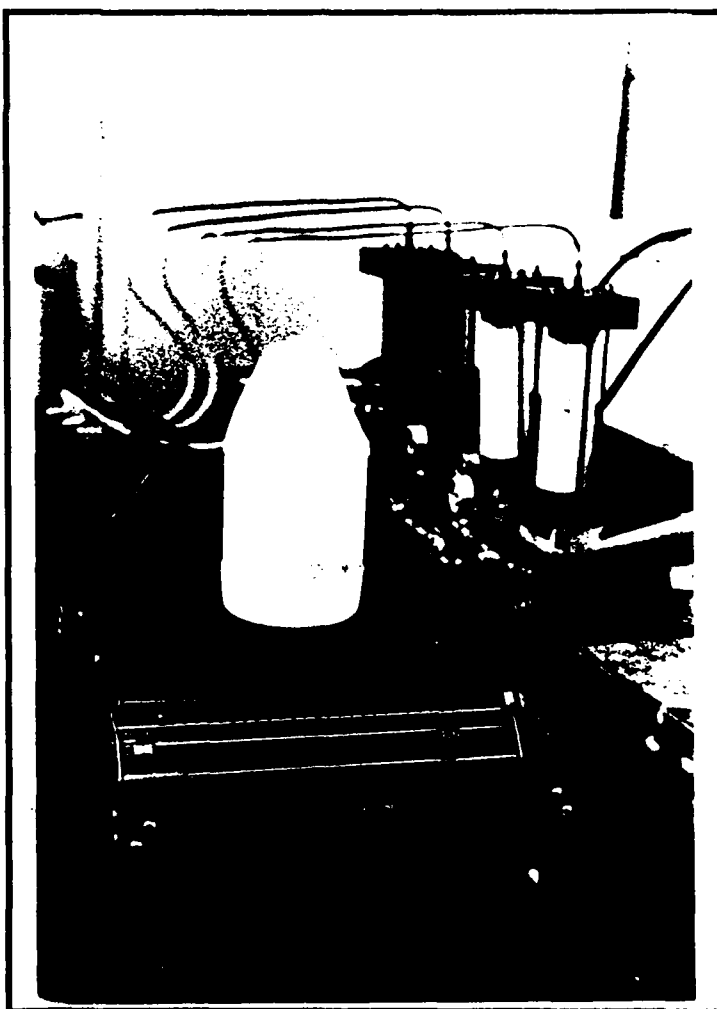
FIGURE 2-5



DETERMINING THE  
WEIGHT OF BRINE WATER  
COLLECTED OVER A  
SHORT PERIOD OF TIME

FIGURE 2-6

DETERMINING THE WEIGHT OF PRODUCT  
WATER COLLECTED FROM A ONE-  
MINUTE FLOW.



- g. Data records: A master data sheet was prepared upon which all data from some 437 runs, along with all appropriate comments, were entered.
- h. Data processing: Over 4000 data bits were entered into a VJCA program (MacIntosh computer) for suitable data reduction. All flows were adjusted for membrane surface area and temperature (25°C = standard temp used). All calculations were output via printer to hard copy.

A second VJCA program was used to apply regression analysis to eleven set of data (a set being the family of data representing one day's run from a given element and representing about 32 separate variables each). Outputs were obtained which included the resulting "fitted" equation of daily flow and its calculated coefficient of correlation.

A third VJCA program was used to determine the first differential of each "fitted" curve and then to calculate the slope of that curve for each hour of an 8 hour period.

## 2.6 Procedures

A specific test protocol was developed and followed to insure that all data were obtained and recorded in a systematic way. Details are specified below:

- a. Each working day constituted a "run". In most cases a run would course a seven (7) to eight (8) hour day. As anticipated, variations from this did occur in some runs.
- b. A run was preceeded by measurements of turbidity in the reservoir tank. If the turbidity was less than the target set for that run, necessary steps were taken to adjust the turbidity prior to commencing the run.
- c. For each run a selected product water-to-brine water flow ratio was achieved by proper valve settings. In some instances the run was preceeded by a "flushing" achieved by fully opening the brine-line valves for several minutes.
- d. Periodically throughout the run, adjustments were made as needed to keep operating conditions reasonably constant throughout a run. Turbidity adjustments were quantitive but brine flow rates were easily adjusted qualitatively by the operator.

e. Since the product water flow was very high compared to the brine flow, it was convenient to measure product water flow in pounds per minute while measuring the brine flow in grams per second. All time intervals were measured by stop watch. Approximately once every two hours the following measures were taken:

- Pounds of product water collected in 60.0 seconds.
- Grams of brine water collected and length of time (to nearest .01 second) taken to collect that much brine.
- Turbidity of feedwater.
- Turbidity of each product line output.
- Turbidity of each brine line output.
- Pressure on main feed line.
- Pressure on each brine line.
- Temperature of water in degrees Fahrenheit.

It was thought that if the brine line was opened to allow a thorough flushing of water across the membrane, some local cleaning would occur and the operational "life" of the membrane would be extended. To study this hypothesis, the operational protocol was modified at the end-of-day shut-down to either include or exclude the effect of periodic flushing as shown below:

- Brine lines were opened fully and the heavy flow allowed to "flush" the system.
- No "flushing" action was taken.

After shut-down, valves were closed to keep water standing on the membranes until the next run. The sump pump in the reservoir was allowed to run 24 hour per day to maintain a fully suspended mixture in the reservoir tank.

## **2.7 Membrane Element Cleaning Chamber**

In order to conserve costs and speed the progress of this work, a VJCA membrane cleaning chamber was improvised by constructing a leusite

"pressure cylinder" and wedding that to an existing ROMEM-type base. Tap water was allowed to flow through the brine chamber of ROMEM base, into the cleaning chamber, and out through an overflow outlet at the top of the cylinder. The membrane element to be cleaned was placed into the clear plastic cylinder so that the effect of cleaning was readily observed. Experience showed that this ROMEM arrangement was particularly convenient for the application of the ultrasonic probe and flushing action during the cleaning activities.

**NOTE:** This improvised cleaning chamber and its operation is presented in an accompanying video cassette in which the viewer will see the packed foulant on the membrane surface then watch as the membrane cylinder is placed into the improvised cleaning chamber. The membrane is subjected to various cleaning protocols including high velocity flushing, mechanical vibration and ultrasonic treatment with two types of ultrasonic probes. The effects are easily seen: Simple back flushing has limited effect. On the other hand, vibrating the membrane while treating it with both a standard and micro tip probe of a Branson Sonic Power Co. Model 350 Sonifier Cell Disruptor produces great clouds of suspended sediments and quickly cleans the membrane.

In use, the fouled membrane element was weighed to obtain a measure of the deposited solids before being placed into the cleaning chamber. The processes observed included:

- a. back flushing through the brine chamber of the ROMEM base.
- b. back flushing and ultrasonic vibration.
- c. back flushing and mechanical vibration.
- d. back flushing, mechanical and ultrasonic vibrations.
- e. use of a detergent in conjunction with combinations of each of the above.

### **3.0 BENCH STUDY RESULTS**

#### **3.1 Ultrafiltration Membrane Description**

The UF elements were supplied as units 6 centimeters in diameter and 30 centimeters long. The elements were procured from the DeSal, Corp., Escondido, California and included two designs:

- a. A "standard" production unit, designated Type 1 in this study, with 8.3 square feet of effective surface area made with three leaves separated by a "standard" plastic fine mesh spacer.
- b. A "special" production unit, designated Type 2 in this study, with 6.1 square feet of effective surface area made with two leaves separated by a "special", spacer.

A third design was manufactured by unwrapping a Type 1 and replacing its spacers by a very open, ladder-type spacer. For purposes of economy and timeliness, this latter spacer was not specifically engineered for this experimental study. A commercially available spacer used in the Ionic Corp. electrodialysis units was adapted for use here. This unit was designated Type 3 in this study (See Figure 3).

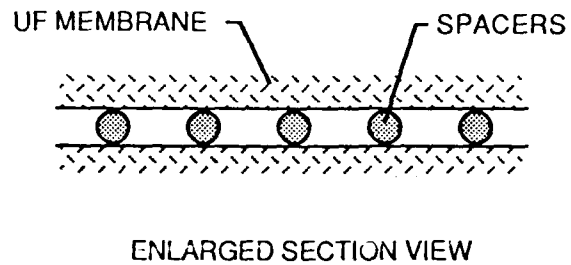
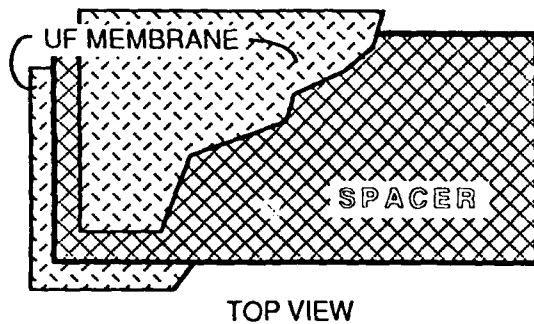
#### **3.2 Coupling Ultrasonic Energy To Membranes Through The Pressure Vessel Wall**

An early intent of this Phase I study was to attach ultrasonic transducers to the outside of the pressure vessels and activate them sequentially so as to induce effective membrane-cleaning vibrations within the chamber. Early literature search, consultation with both BRDEC and other personnel and VJCA observations indicated that it would be more efficient and less complicated to resonate the flushing water with ultrasonic probes. The latter procedure was pursued from that point.

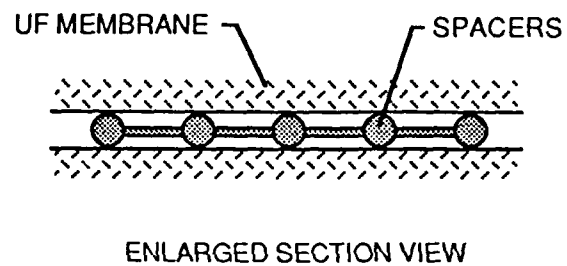
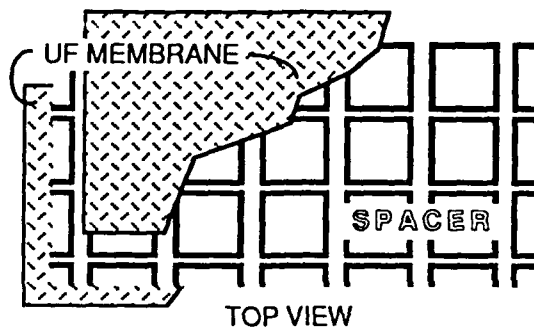
#### **3.3 Membrane Fouling In Association With Different Spacers And Feedwater Of Various Turbidities**

Three types of spacers were employed in this study: commercial standard, commercial special, and the adapted ladder-type spacer (Ionics Corp). A total of eight UF elements were subjected to study. These were divided into two cohorts of four each. The studies conducted on these cohorts are given below.

### TYPE 1: COMMERCIAL STANDARD



### TYPE 2: COMMERCIAL SPECIAL



### TYPE 3: LADDER TYPE SPECIAL

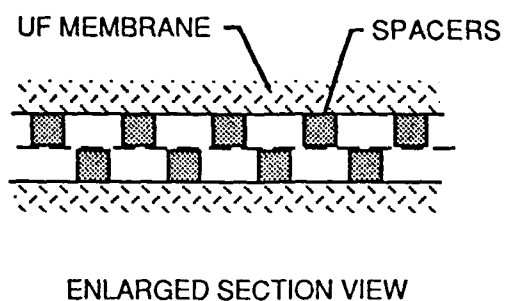
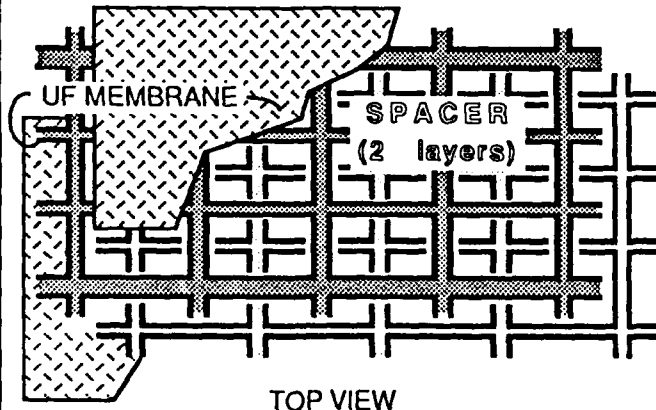


Figure 3

DIAGRAMS OF TYPE 1, TYPE 2 and TYPE 3 SPACERS

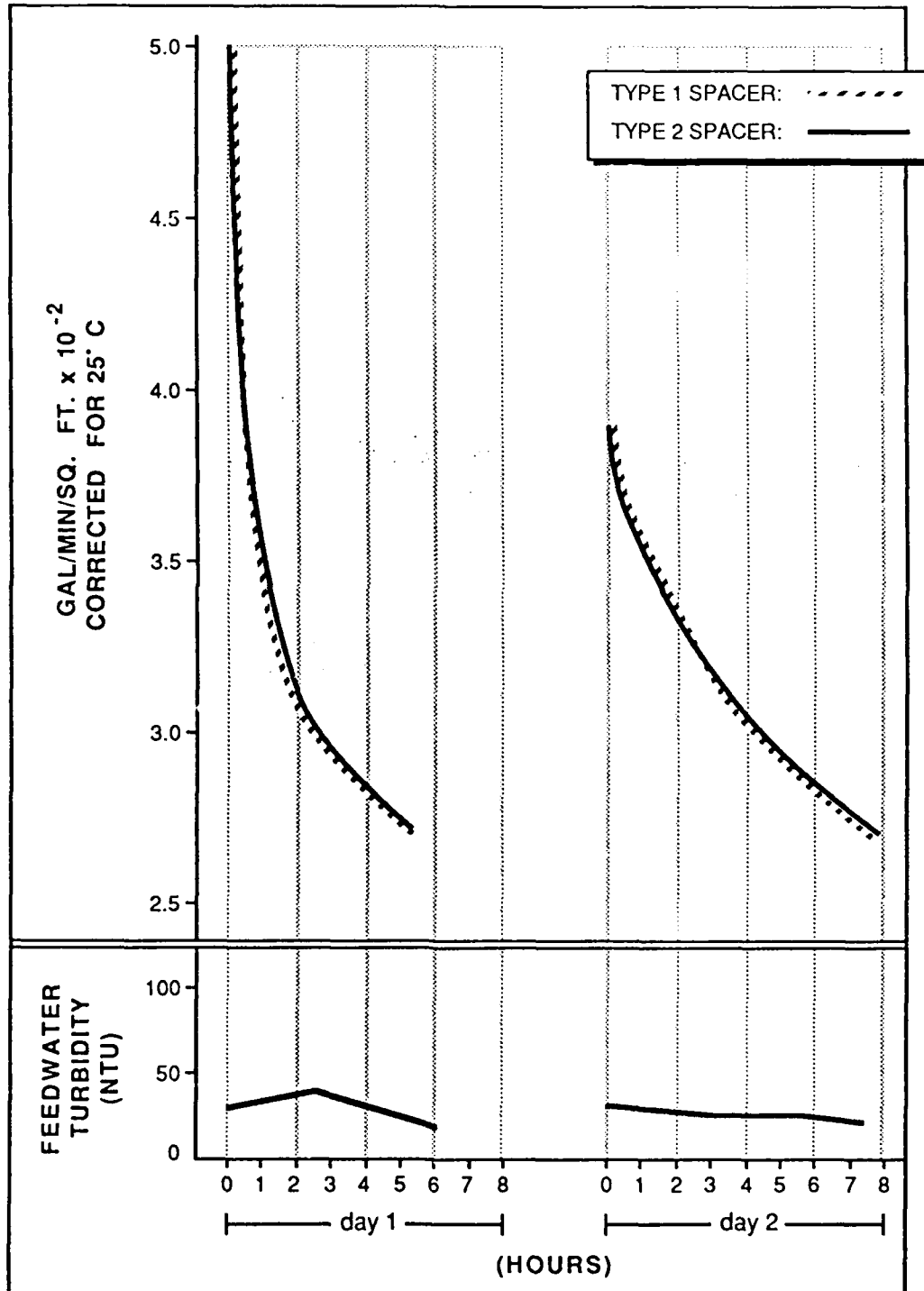
- a. Four new elements were employed in this experiment. Two had Type 1 spacers and two had Type 2 spacers. Elements using Type 1 spacers (plastic mesh with approximately 3.2 square holes per cm) were designated with a "T". These filters had three leaves for an effective .77 square meters (8.3 square feet) surface area. Specifically two such elements were used: Serial No. 109T in pressure vessel unit No.1 in the experimental set-up and Serial No. 108 in pressure vessel unit No. 3.

The Type 2 spacers used in the UF commercial special membranes were characterized by plastic "rods", separated by about 6 millimeters, running the length of the filter. These "rods" were about 20 millimeters in diameter with cross rungs or "steps" linking the rods. These steps were about 1 millimeter in diameter and were linked to connect the middle of the rods. Thus cross rungs were not in contact with the membrane when the element was not under pressure. Cross rungs were about 6 millimeters apart. Another feature of these special elements is that they consist of only two leaves and, therefore offer a surface area of .56 square meters (6.3 square feet). Two such elements were used: Serial No. 101 TX in pressure vessel unit No. 2 and Serial No. 100 TX in pressure vessel unit No. 4.

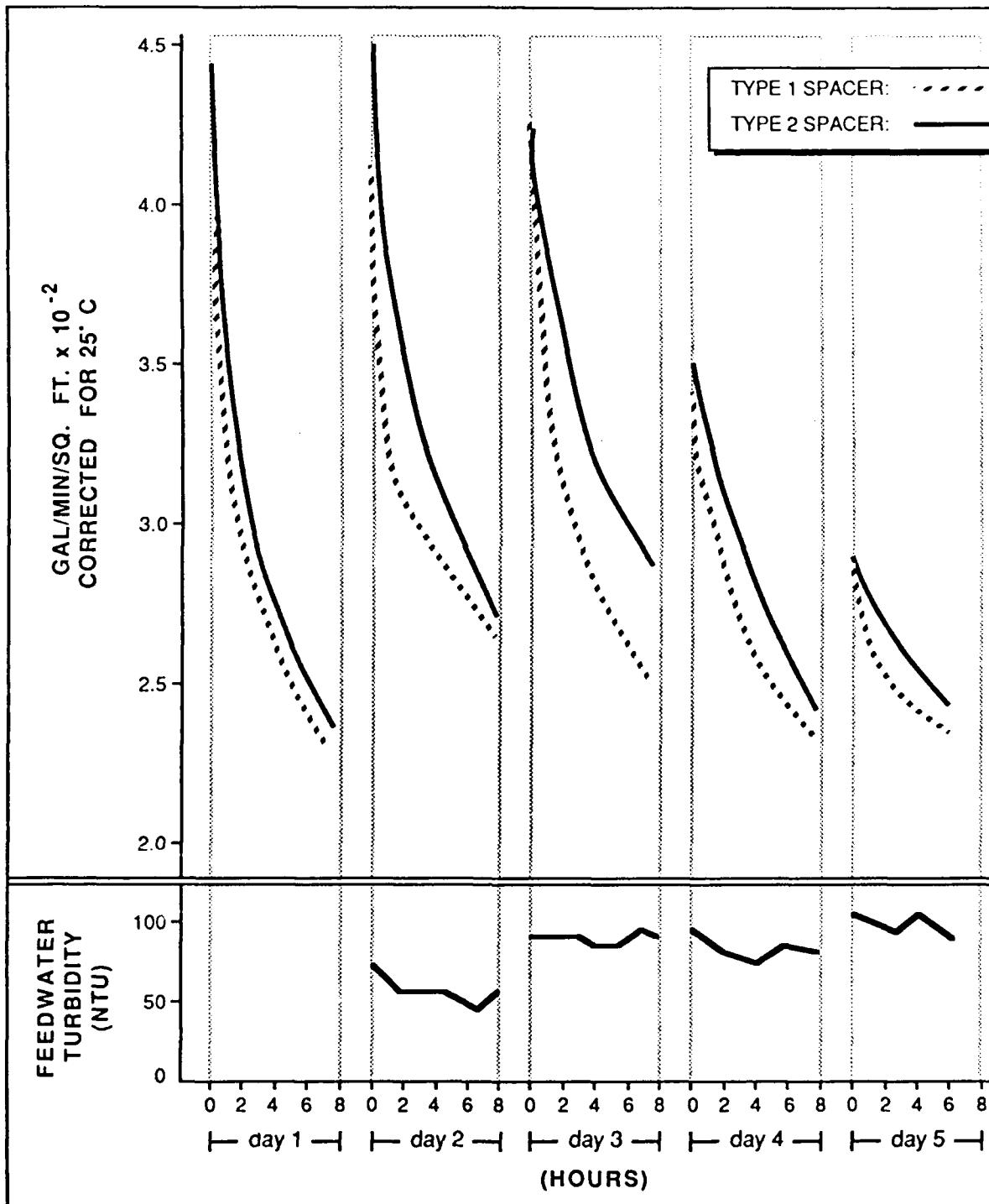
Three separate studies were conducted with this arrangement:

- **Study 1:** Two runs were conducted under conditions of low turbidity (less than 30 NTU) with 2 minute flushing after each daily run and consisted of a set of four measurements over an eight hour period. Brine lines were flushed for 60-90 seconds at the end of each day. Feedwater turbidity was held to between 20-30 NTU during these runs. Data from these runs are summarized and shown in **Graph 1**.
- **Study 2:** Five runs were conducted under conditions of increasing turbidity with flushing after each daily run. Turbidity in the feedwater was increased daily from an average of approximately 30 NTU to about 100 NTU. Data from these runs are summarized and shown in **Graph 2**.
- **Study 3:** Seven runs were made under conditions of high turbidity (greater than 100 NTU) with no flushing between day-to-day operation. After each run the pressure vessels were isolated by closing inflow and outflow valves. No flushing action was taken. Data from these runs are summarized and shown in **Graph 3**.

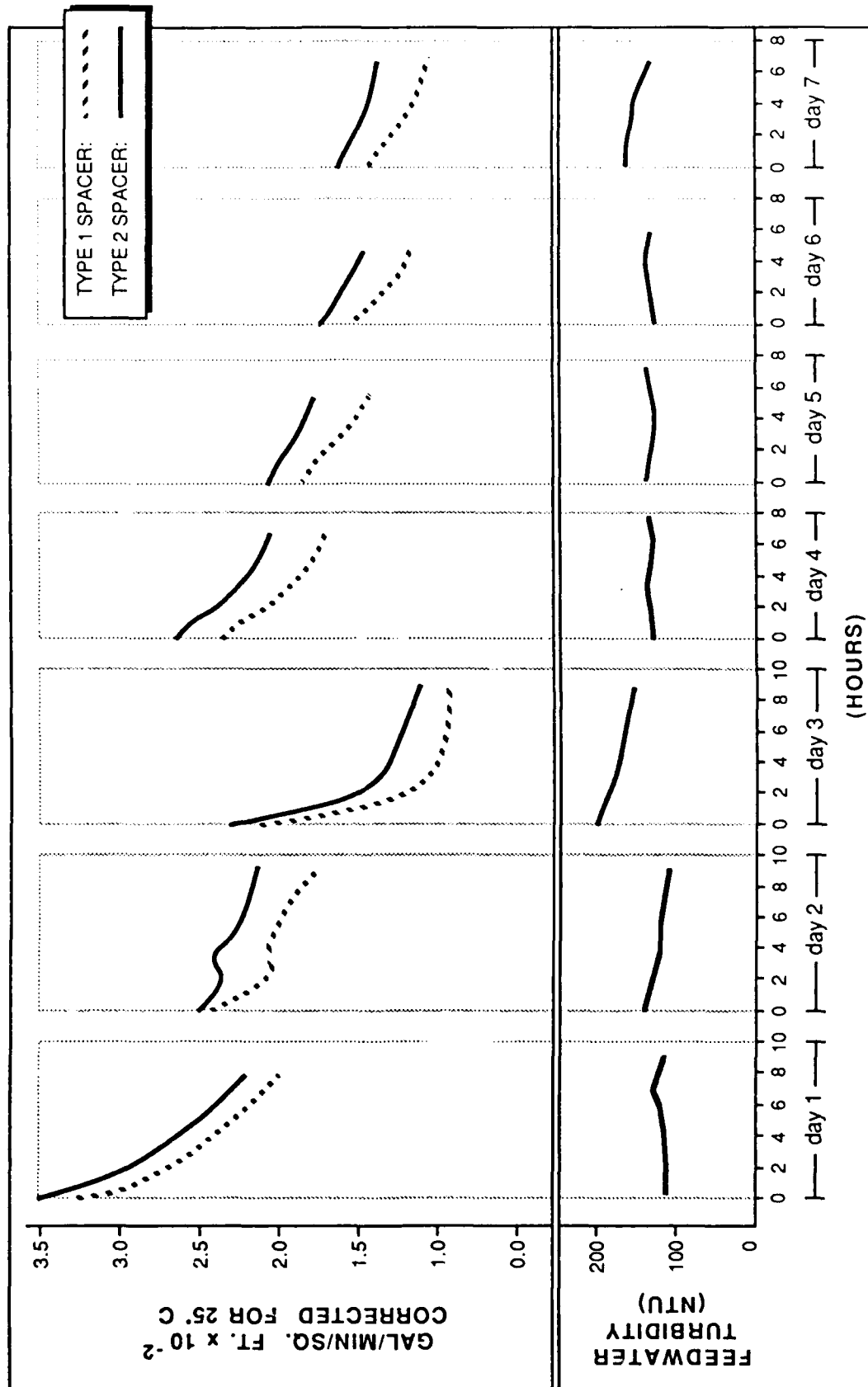
Graph 1  
PRODUCT WATER FLOW THROUGH UF MEMBRANES  
WITH TYPE 1 and TYPE 2 SPACERS  
WITH ONCE DAILY FLUSHING



Graph 2  
 PRODUCT WATER FLOW THROUGH UF MEMBRANES  
 WITH TYPE 1 and TYPE 2 SPACERS  
 WITH ONCE DAILY FLUSHING  
 (INCREASING TURBIDITY FEEDWATER)



Graph 3  
 PRODUCT WATER FLOW THROUGH UF MEMBRANES  
 WITH TYPE 1 and TYPE 2 SPACERS  
 WITHOUT DAILY FLUSHING  
 (INCREASING TURBIDITY FEEDWATER)



- b. Four new UF elements were employed in preparing this second cohort for study. One had a Type 1 spacer and one a Type 2 spacer. The other two had Type 3 spacers specially prepared at the VJCA laboratory by unwrapping two UF elements with Type 1 spacers, removing the spacers, and replacing those spacers with the plastic "ladder-type" spacer as used in the Ionics Corp. electro dialysis units.

This Type 3 spacer featured vertical support columns with cross-connecting "steps". The column and steps were flat and lay flat against the membrane surface. A single spacer consisted of two such devices, glued together, arranged so that the "ladder" cross-bars were staggered: the cross-bars on the "bottom" lay half-way between the cross-bars on the "top". (See **Figure 3**)

This cohort was used to study UF element performance under conditions of increasing and excessive turbidity in the feedwater.

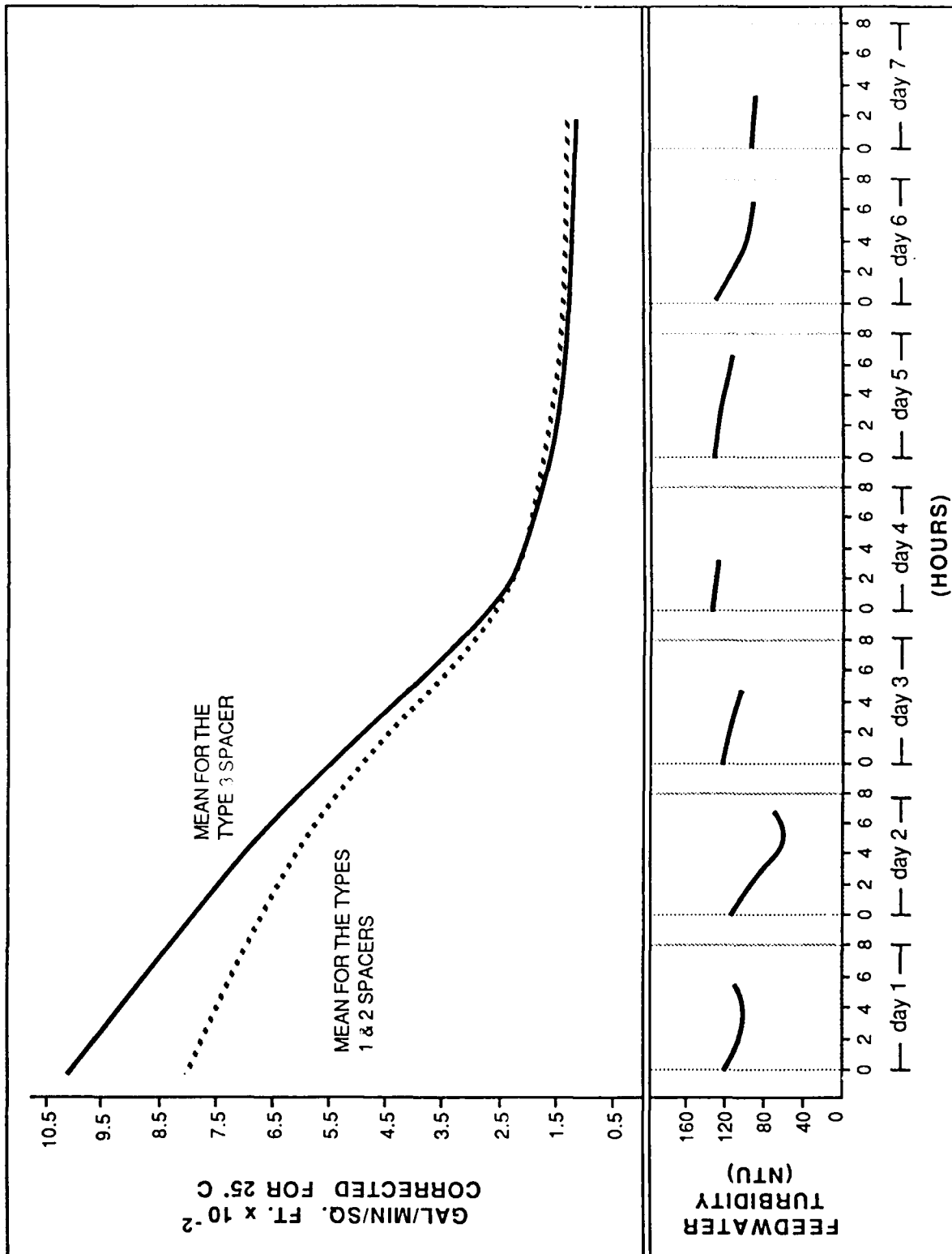
- **Study 4:** The UF elements fitted with these Type 3 spacers were positioned in pressure vessels 1 and 4; the Type 1 spacer element in pressure vessel 2; and the Type 2 spacer in pressure vessel 3. The turbidity of the feedwater was held between 125 NTU and 150 NTU throughout these runs.

The effective surface area of the UF elements using the Type 3 spacers was significantly diminished due to the geometry of this spacer. Consequently, the effective surface area of the UF membranes, was estimated by calculating the "holes" in the ladder, and taking into account the staggered character of the cross-bars. This yielded a reasonable estimate of the effective surface area which was used throughout the study. Data obtained over 7 runs of this work are summarized and shown in **Graph 4**.

### 3.4 Membrane Cleaning

Once the fouled UF elements were removed from the pressure vessels, they were kept in a water bath to prevent drying. The individual elements were placed into the cleaning unit described earlier for cleaning. The basic cleaning techniques included the separate and combined treatment(s) of backflushing, mechanical shaking, detergent action, and the use of ultrasonic energy probes. In all cases, the elements stood "on end" during all phases of the cleaning process. (Please also see the accompanying Video-Tape as mentioned earlier in this report).

Graph 4  
 PRODUCT WATER FLOW THROUGH UF MEMBRANES WITH  
 TYPE 1, TYPE 2 and TYPE 3 SPACERS,  
 NO FLUSHING OCCURED AND FEEDWATER TURBIDITY WAS VERY HIGH.



- a. The UF elements were readily cleaned and the following actions were observed in the process:
- Backflushing dislodged the accumulated material in large particles. These peeled away from the membrane and were generally carried up to the discharge opening in the cleaning chamber.
  - Mechanical vibration of the UF element loosened much more "caked" material and greatly aided in its removal. However, large agglomerated particles did predominate--and these were not readily carried to and through the discharge opening of the cleaning chamber.
  - Use of the Branson Sonifier ultrasonic probe quickly converted the accumulated colloidal deposits into a finely-divided dispersion which was readily carried to and through the discharge opening. With the ultrasonic energy directed through the element spacers, the scouring action on the membrane was very efficient and caused no apparent damage to the membrane so long as the probe tip did not physically penetrate the membrane.
  - The (new and wet) UF elements weighed about 1.3 lbs before use. After the internal gross fouling they weighed about 2.5 lbs. After cleaning, the UF elements were effectively returned to their former wet weight. (Table 1).

### **3.5 Measured Performance of Cleaned Membranes**

The measured weights of unfouled, grossly fouled and cleaned UF elements are summarized and shown in Table 1.

- a. From the cleaned UF elements, four, two having the improvised (i.e. from the Ionics Corp electrodialysis units) ladder-type spacer and one each of the Type 1 and Type 2 spacers, were placed back into the pressure vessels and run at the same pressures as was used previously but with a relatively low turbidity feedwater. Averaged results are summarized and shown in Graph 5.

**TABLE 1**

**Measured Weights of Unfouled, Grossly fouled and  
Cleaned UF Elements**

PRESSURE VESSEL	ELEMENT IDENTITY	WEIGHT OF MEMBRANES IN POUNDS			
		DRY	FOULED	CLEANED	DIFFERENCE
1	TYPE 3	1.05	2.30	1.30	1.00
2	TYPE 1	0.98	2.30	1.20	1.10
3	TYPE 2	0.98	2.10	1.20	.90
4	TYPE 3	1.05	2.20	1.50	.70

**3.6 Discussion**

During this first phase VJCA efforts were directed towards the demonstration of three objectives:

First, to determine the effectiveness of different and innovative spacers on the fouling rates of membranes.

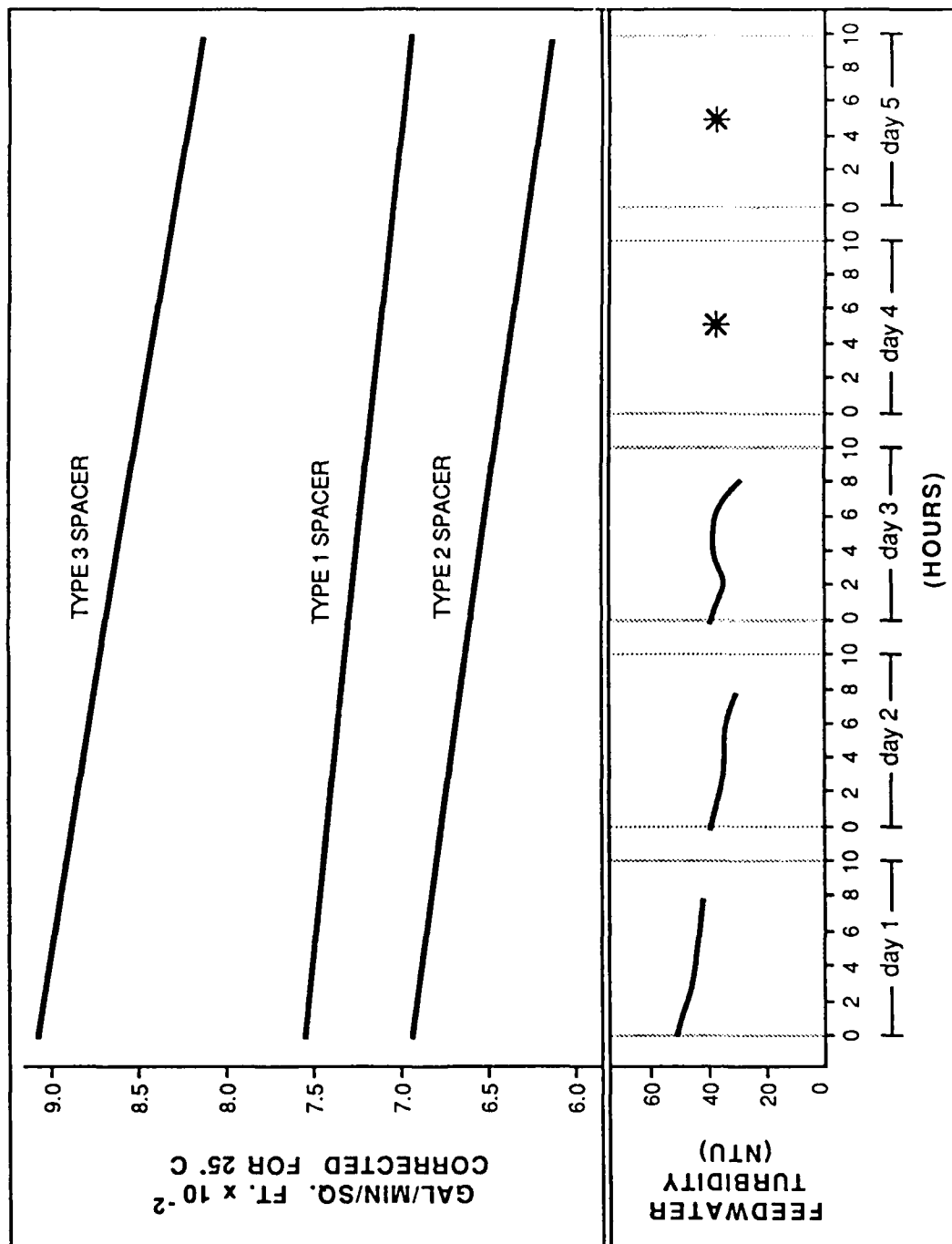
Second, to determine the relative effectiveness of ultrasonic enhanced cleaning protocols.

Third, to determine the degree of cleaning as measured by the weight loss of adhered material and the water production performance after ultrasonic enhanced cleaning had been accomplished.

The project efforts examined three typical "off-the-shelf" spacers to determine if this approach of innovative spacers would enhance removal of foulant and/or reduce fouling rate. The data collected indicates that the spacer design indeed does have an effect on fouling rate and that such changes in spacer design could significantly enhance the reduction of fouling. This is especially true and promising since the spacers tested were not specifically designed for the application used here, but were off-the-shelf spacers which did show a significant reduction in fouling rate. Specific spacer designs with features that promote enhancement of element performance and cleaning along with additional testing engineering and data analyses are planned for expanded studies in Phase II of this SBIR program effort.

The cleaning protocols used in this Phase I study were simple. They consisted of backflushing, mechanical shaking, limited detergent action, and

Graph 5  
TREND IN THE APPROXIMATE PRODUCT WATER FLOW THROUGH UF MEMBRANES  
USING TYPE 1, TYPE 2 and TYPE 3 SPACERS,  
AFTER MEMBRANES HAD BEEN CLEANED WITH ULTRASONIC ENGERY.



\* No measurements taken but turbidity stayed approximately the same as days 1, 2 and 3.

use of an ultrasonic energy probe. Each of the methods had a removal effect on the adhered material, but the only method which provided full removal of the dirt and foulants was the ultrasonic probe. Comparatively speaking, in every case where cleaning was tried by a method other than the ultrasonic probe, more adhered material was removed when the probe method was used.

The Branson Sonifier Ultrasonic probe was also an "off-the-shelf" device. There was no attempt here to design nor fabricate such a probe for this specific membrane cleaning application. Two different ultrasonic probe heads were used. Although the results observed were essentially the same, indications are that the smaller head, high energy probe may have more promise for this cleaning application. The ultrasonic probe enhanced foulant removal from the membrane by a vibratory scouring effect and further dispersed the larger particles to fine silt which was quickly flushed from the system. In all cases the elements were essentially brought back to their original (i.e., unfouled) weight by the ultrasonic enhanced cleaning. In Phase II it is projected that specific engineering design of the probe and innovative spacers, coupled with various new chemical cleaning solutions for maximum effect, will cause UF element life to be extended for a significant time. This in turn will lead to better cost efficiency and economy in the application of RO technology.

This Phase I study has shown that even when the objective is only to demonstrate feasibility, the ultrasonic probe cleaning technique is highly effective, easy to use and may potentially eliminate the need for further cleaning agents. In any case the use of new and more effective spacers in the ultrafiltration system will enhance cleaning, reduce the fouling rate and protect the RO elements from excessive fouling. Specific methodologies and prototype hardware will be developed in Phase II to optimize the effects demonstrated to date.

## 4.0 CONCLUSIONS

Based on these SBIR Phase I studies to determine the technical feasibility of the use of special spacers to reduce the rate of fouling and ultrasonic-enhanced cleaning of fouled UF membranes. It is concluded that:

- 4.1 For higher turbidity feedwaters, i.e. greater than 50 NTU, Type 2 and Type 3 spacers provide better UF membrane performance than Type 1 spacers.
- 4.2 The effectiveness of ultrasonic energy to assist the cleaning of membranes is better achieved by resonation of the cleaning media (water solution) using internal transducers rather than externally coupled transducers mounted on the pressure vessels.
- 4.3 It is feasible to significantly enhance the effective cleaning of grossly fouled UF elements using ultrasonic "cleaning" probes.
- 4.4 Cavitation-generated bubbles from cell disruptive ultrasonic devices effectively disperse clay material from fouled UF membranes elements.

## 5.0 RECOMMENDATIONS

It is recommended that BRDEC:

- 5.1 Continue research and development efforts to further develop these advanced innovative technologies by entering Phase II of this SBIR program effort. Include in Phase II the following specific tasks:
- Experimental studies to document the innovative spacers and ultrasonic enhanced cleaning of fouled reverse osmosis (RO) membrane elements.
  - Specifically design, fabricate and employ ladder-type spacers in the RO elements to be studied.
  - Specifically design and fabricate ultrasonic transducers (either probe type or mounted internally in the pressure vessels) for the purposes of enhancing the RO elements cleaning process and/or in situ hindering of the fouling process.
- 5.2 Request and support the SBIR Phase II technical and cost proposals to be submitted by VJCA Inc.

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